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Design, Fabrication, and Testing of a Sugar Base Solid Propellant Rocket Motor

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***Abstract*: In this work, Solid rocket motors Upper closer, combustion chamber, and nozzle analysis and integration into a single unit. The combustion chamber of the solid rocket motor is constructed using a CPVC Pipe, with a connected Composite nozzle and a CPVC upper closure attached to the pipe's end by screwing, the experimental methodology centered on examining the thrust in the motor, with a concurrent analysis on the expansion of gases and the thrust generation through nozzle interchangeability. These experiments tested a new methodology to integrate a rocket motor by conducting a static test, specifically concentrating on the CPVC operating pressure in high-temperature resistance capability. The propellant employed is KNSU (a mixture of potassium nitrate and sugar). The findings indicate that the combustion chamber made of CPVC demonstrates resilience in the higher section of the nozzle. Additionally, the cold-pressed KSNU propellant exhibits an exponential relationship between the instantaneous burning rate and the pressure within the chamber.**

***Keyword*: Solid Rocket Motor, KNSU, CPVC**

I. INTRODUCTION

The rocket's propulsion system plays a fundamental role in aerospace engineering, determining the trajectory and success of a mission. At the heart of this system lies the rocket motor, a sophisticated assembly consisting of crucial parameters and components such as burn duration, thrust, temperature, nozzle, combustion chamber, liner, and upper closure. This study aims to meticulously examine the complexities of the rocket motor through a static testing regimen, focusing on the precise design and fabrication of its constituent elements. Within this intricate assembly, the propellant composition takes on utmost importance.

The KNSU propellant, a combination of Potassium Nitrate (KN) and Sugar (SU) in a specific 65:35 ratio, serves as an exemplary solid rocket propellant optimized for performance. [1] Potassium Nitrate acts as a stabilizing oxidizer, ensuring sustained combustion, while Sugar serves as a fuel, enabling controlled combustion and enhancing overall energy content. Based on availability, the potassium nitrate and sugar blend stand out as the optimal propellant choice.

We considered a range of materials such as stainless steel, titanium alloys, aluminum alloys, and composites for the combustion chamber. Nevertheless, we opted for [3] CPVC due to its moderate operating pressure, heat resistance, and availability, suitable for an I-class motor. Nozzle and upper closer is a modification in CPVC pipes. The analysis and Dimensions are achieved by Richard Nakka's SRM Excel Sheet and Open Motor Software which allow usable data. The temperate transfer after burning of fuel is slowed down by insulating material (liner) between the fuel and combustion chamber.

II. REVIEW OF LITERATURE

Before delving into the primary goal of this endeavor, it is essential to initially introduce certain definitions and fundamental physical concepts. The initial concept, introduced by Richard Nakka, revolves around the propellant, which is defined by its fuel and oxidizer composition, as well as the casting geometry. [2] Nakka asserts that the thrust curve of the motor is influenced by the propellant's geometry. The analysis of the combustion chamber can be conducted by examining its operational pressure and capability to withstand temperature, [3] CPVC exhibits favorable performance under supported internal pressure, withstanding pressures of up to 160 bars, but it tends to display brittle behaviour. In contrast, the pipe can endure pressures of up to 70 bars and demonstrates ductile behavior.[2]

The objective of designing a rocket nozzle is to maximize the exit velocity of combustion products. This involves creating the appropriate geometric profile for the nozzle to achieve isentropic flow. Isentropic flow relies solely on the cross-sectional area, requiring frictionless and adiabatic conditions (no heat loss) [4]. Consequently, it is crucial in the actual nozzle design to minimize factors like friction, flow disruptions, and conditions that may result in shock losses. Additionally, efforts are made to reduce heat transfer losses, ensuring that the flow properties closely align with isentropic conditions, primarily influenced by the changing cross-sectional area as the fluid progresses through the nozzle.

III. MATERIALS & METHODS

CPVC is utilized as the combustion chamber, while a modified composite material of CPVC is employed in the upper closure and nozzle, Sandpaper acts as an insulator to prevent the thermal exchange of heat from combustion to the pipe. These materials are chosen based on dimensional requirements and availability. The KNSU propellant is a combination of Potassium Nitrate (KN) and Sugar (SU) in a specific 65:35 ratio.

TABLE I: DESIGN PARAMETERS

S/N	Parameters	Values	Units
1	Chamber Pressure	350	Psi
2	Combustion Chamber Diameter	44	mm
3	Combustion Chamber Length	250	mm
4	Core Diameter	20	mm

3.1 Theoretical Analysis

The examination is conducted using Richard Nakka's solid rocket motor (SRM) design Excel sheet, which aids in analyzing nozzle geometry as well as thrust, pressure, and temperature. Additionally, an open motor configuration provides a secondary confirmation, allowing the entire process to be tested under various conditions. The optimal range is then selected and verified.

According to the selected design parameter in Table I, result parameters are,

TABLE II: RESULT PARAMETERS FROM SRM EXCEL SHEET

S/N	Parameters	Values	Units
1	Max Chamber pressure	272	Psi
2	Burn Time	1.13	S
3	Max Thrust	581	N
4	Average Thrust	535	N
5	Total impulse	608	N-sec
6	Propellant Grain Mass	0.541	Kg
7	Specific Impulse	114.7	Sec
8	Max Kn	113	

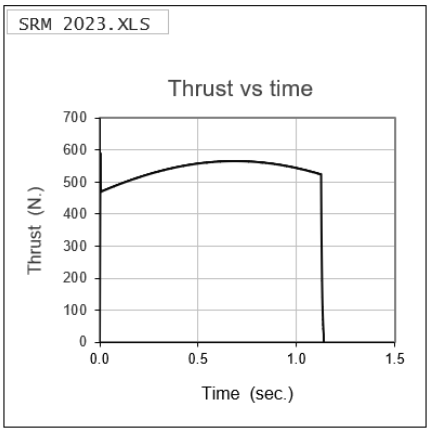


Fig. I Thrust vs Time graph By SRM Excel Sheet

TABLE III: RESULT PARAMETERS FROM OPEN ROCKET

S/N	Parameters	Values	Units
1	Average Chamber pressure	336.94	Psi
2	Burn Time	1.11	S
3	Max Thrust	810	N
4	Total impulse	602.42	N-sec
5	Propellant Grain Mass	0.54	Kg
6	Specific Impulse	114.7	Sec
7	Max Kn	164	

Ongoing analysis identifies the optimal range for this dimension, and we assess our specified burn profile characteristics. Based on this analysis, the thermal insulation layer is selected accordingly.

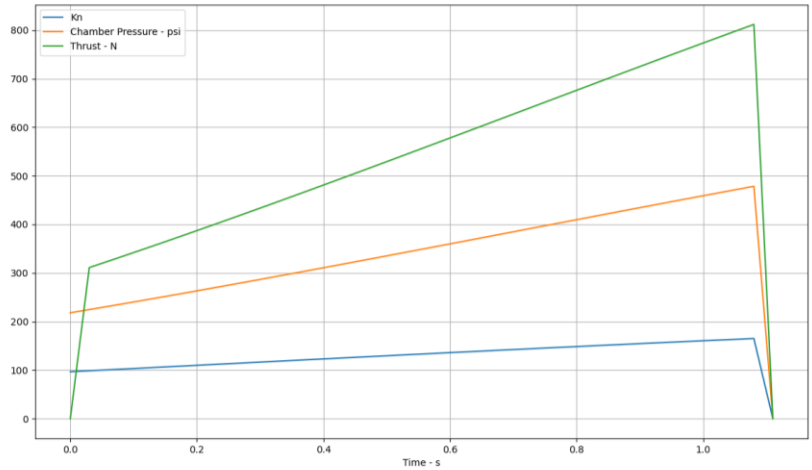


Fig. II Open Motor Simulation

This data gives a brief of how the motor is going to perform both data from both simulations are not exactly correct enough but its close enough in case of burn time and specific impulse, total impulse.

3.2 Combustion Chamber - CPVC

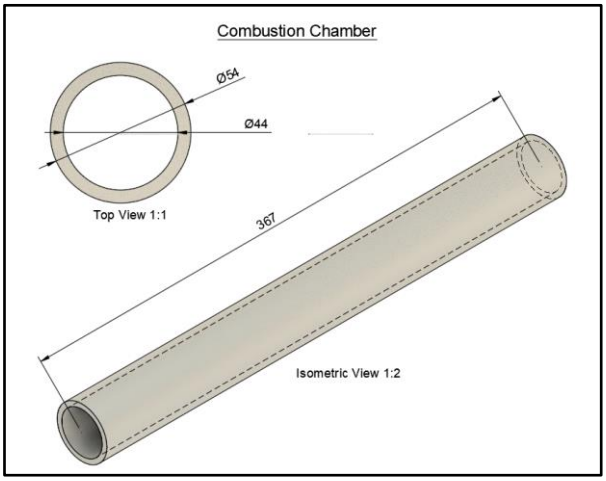


Fig. III Combustion chamber CAED model

The combustion chamber is assembled using a 5mm thick CPVC material, incorporating a schedule 40 SDR 11 pipe that spans 367 mm. It is engineered for operation under standard temperature conditions, with an initial operating pressure of 70 bars. Somehow the CPVC is designed to resist high temperatures, in our specific scenario, the temperature rises rapidly a few seconds into the burn due to the motor's design for a 4-second burn.

As a result, the inner wall experiences elevated temperatures after the insulator has burned away. The chamber pressure during this phase is maintained at 350 psi.

3.3 Upper Closer CPVC

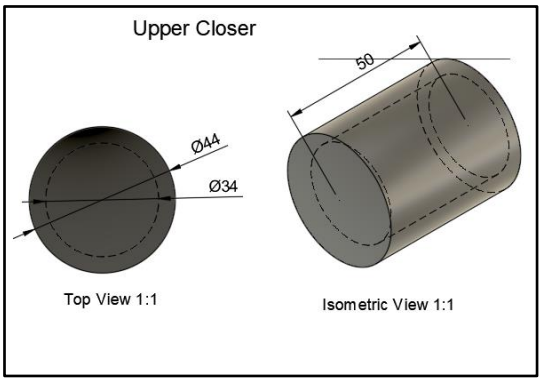


Fig. IV Upper Closer 3D Model

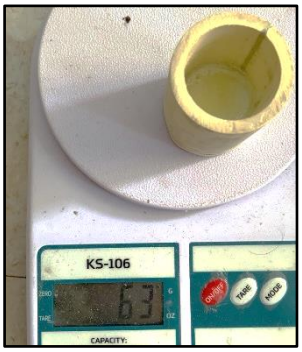


Fig. V Upper Closer in Physical and Weighted

The upper closure is crafted from the same combustion chamber material, achieved by removing a side piece to reduce its diameter to match the inner diameter of the combustion chamber. The process involves marking the desired perimeter, cutting, and securing with a hose clamp. Subsequently, the assembly is immersed in boiling water for 5 minutes, and this procedure is repeated until the two joints are securely joined

Following this procedure, the sides are bonded using a combination of PVC powder and 743 instant glues. The bottom side is crafted from flattened CPVC, conforming to the combustion chamber's diameter. From the top, Araldite epoxy adhesive is poured to both prevent leakage and enhance structural strength.

3.4 Nozzle

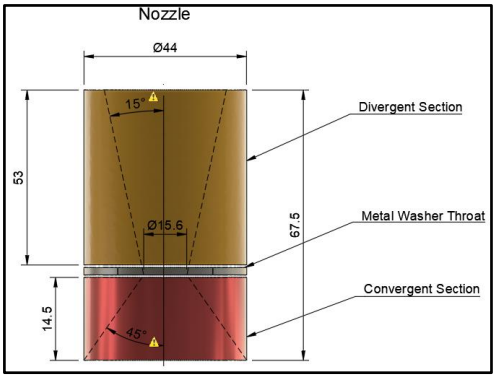


Fig. VI Nozzle 3D Model

Fig. VII Nozzle Divergent and Convergent section

The nozzle has been made in 3 parts…

3.4.1 Divergent Section

The cylindrical PVC is cut to specified dimensions, and its diameter is decreased, mirroring the upper closure. Additionally, the divergent section is removed more than the given dimensions, and a

fillet is applied. This fillet is then extruded according to the dimensions of the die. The resulting upper layer forms a barrier to prevent the burnout of the divergent section as in the FIGURE :3.6.

3.4.2 Metal Washer Throat

This is a standard bold washer featuring an inner diameter of 15.6mm and a thickness of 2mm. It is positioned between the divergent and convergent sections to mitigate throat erosion.

3.4.3 Convergent Section

The procedure for creating this section is identical to that of the divergent section.

3.5 Screw

Fig. VIII 18mm Self-Drilling Screw

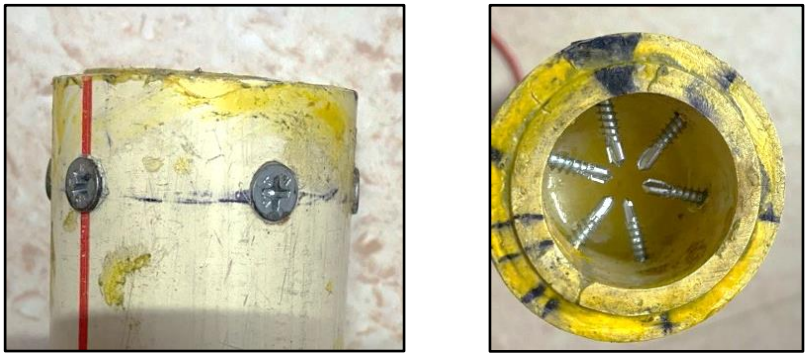


Fig. IX Screwed on Combustion and Chamber Upper Upper closer

The inclusion of a screw provides additional security to the nozzle and upper closure, preventing them from dislodging. This screw can be self-drilled easily in CPVC

3.6 Sand Paper (Liner)

The sandpaper serves as an insulating layer, shielding the combustion chamber from excessive heat and burning. It combusts along with the propellant towards the conclusion of the process, and the

specific grade employed is 80 grits. Additionally, it proves beneficial during the casting of the propellant.

3.7 Propellant Casting

The casting of KNSU fuel involves combining potassium nitrate and sugar in a 65:35 ratio. This mixture is cooked in a non-stick pan at 150 degrees for a continuous 4-minute duration, with thorough mixing.

Fig. X Propellant after Casting

3.8 Assembling

The motor integration commences by applying CPVC glue and screwing in the nozzle. The fuel grains, accompanied by the insulator, are then inserted, and finally, the upper closure is affixed using CPVC glue, inserted, and secured with screws.

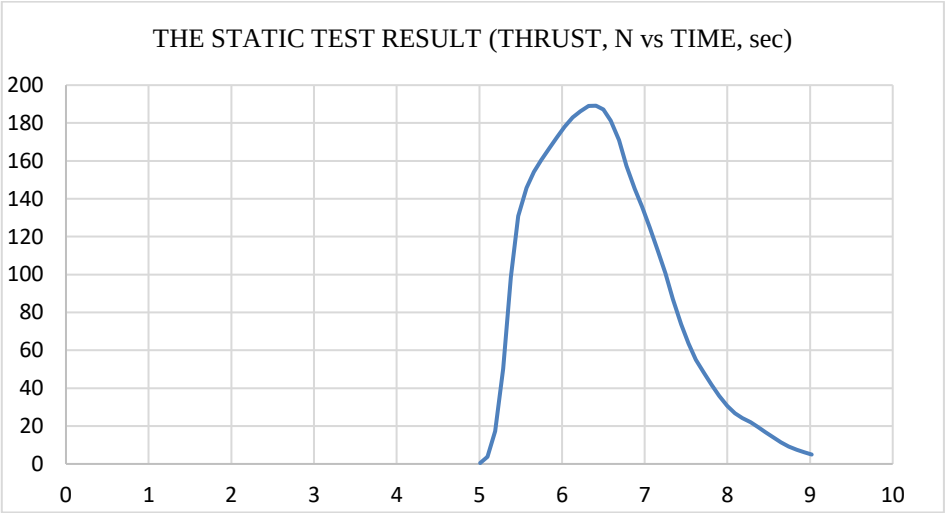
IV. RESULT & DISCUSION

The motor undergoes a static test on a horizontal static test pad, and the data is gathered and stored on an SD card.

TABLE IV: RESULT FROM STATIC TEST

S/N	Parameters	Values	Units
1	Propellant Grain Mass	0.4	Kg
2	Max Thrust	189.1474	N
3	Average Thrust	102	N

4	Burn Time	4	S
5	Total Impulse	394	N-sec
6	Specific Impulse	98.5	Sec



GRAPH I Static Test Result (Thrust, N vs Time, Sec)

Based on both theoretical and practical data, discrepancies are evident, primarily attributed to combustion loss, nozzle erosion, and errors in the static test pad. The burn time has extended from 1.1 seconds to 4 seconds, with an average thrust of 102 N. There is also a reduction in total impulse, along with a combustion efficiency decrease to 0.7. Despite these variations, the data provides values that are closely aligned. The nozzle experiences significant erosion due to the elevated mass flow rate, resulting in a reduction of chamber pressure. The upper section of the convergent region within the combustion chamber undergoes more profound burning.

V. CONCLUSION

In this research paper, we designed and fabricated sugar sugar-based solid propellant rocket motor, and the motor was tested. We were very close to the theoretical data when the practical data was collected. The integration of a CPVC combustion chamber, composite nozzle, and CPVC upper closure showcased a meticulous approach to motor assembly, with a focus on resilience and high-temperature resistance.

The utilization of KNSU propellant, a blend of potassium nitrate and sugar, demonstrated great results in terms of burn profile and performance.

The theoretical analysis, conducted using Richard Nakka's SRM design Excel sheet and Open Rocket software, gave us an understanding of the motor's behavior during the test.

The challenges encountered, include nozzle erosion and combustion inefficiencies. The inefficiencies could be due to the impurities in the fuel. The findings of this study contribute to the broader field of amateur rocketry, emphasizing the potential of CPVC pipe motors for medium-range flights.

VI. FUTURE SCOPE

CPVC pipe motors have the potential for enhancement and utilization in amateur rockets for medium-range flights. Improvements can be made to the nozzle to withstand erosion, and experiments with new propellants can be conducted on a redesigned static test pad. Additionally, alterations to the liner material are possible. Given that the upper section of the convergent part of the combustion chamber undergoes more intensive burning, enhancing insulation in that area can effectively prevent excessive burning.

VII. ACKNOWLEDGEMENT

We express our sincere gratitude to Mr. Richard Nakka for his invaluable contributions to our research, particularly for providing access to his Excel sheet for simulations. We extend our sincere appreciation to Open Motor software, which played a pivotal role in the simulation.

We extend our appreciation to Fusion360 for its role in the 3D modeling phase of our project.

VIII. REFERENCES

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